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Multimodal assessment of early kidney allograft complications: Role of renal scintigraphy and laboratory biomarkers

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Abstract. *Early post-transplant complications remain a major challenge in kidney transplantation. It reveals an overlap of clinical manifestations and the limited specificity of routine laboratory markers may delay diagnosis. Functional renal scintigraphy provides a quantitative assessment of graft perfusion and function and may improve early detection of allograft dysfunction.*

Objective. To evaluate the predictive value of scintigraphy, clinical and laboratory parameters for early post-transplant complications in kidney transplant recipients.

Methods. This single-center observational study included 65 kidney transplant recipients who underwent 99mTc-DTPA renal scintigraphy within 1-7 days after transplantation. Conventional laboratory markers (serum creatinine, blood urea, white blood cell count, erythrocyte sedimentation rate, platelet count) and scintigraphy indices, including perfusion index (PI), functional index (FI), and glomerular filtration rate (GFR), were analyzed. Patients were classified into stable graft function and complication groups. Statistical analysis included multivariable logistic regression, receiver operating characteristic (ROC) analysis, and principal component analysis (PCA).

Results. Thirty-three patients (50.8%) developed early post-transplant complications. Serum creatinine and platelet count were significantly higher in the complication group ($p < 0.05$). Multivariable regression identified serum creatinine, ESR, PI, FI and GFR as independent predictors of complications, with GFR demonstrating the strongest inverse association ($p<0.0001$). ROC analysis showed good diagnostic performance for PI (AUC 0.78-0.82), FI (AUC 0.75-0.80), and GFR (AUC 0.73-0.78). PCA demonstrated clustering of scintigraphy indices with markers of graft dysfunction and inflammation, supporting their complementary diagnostic value.

Conclusions. Functional renal parameters, particularly PI, FI and GFR, provide significant predictive value for early kidney allograft complications and outperform routine laboratory markers when used in isolation. An integrated approach combining laboratory and scintigraphy assessment may improve early risk stratification and guide timely clinical interventions in the post-transplant period.

Key words: *kidney transplantation, postoperative complications, radioisotope renography, technetium tc 99m pentetate, perfusion index, functional index, glomerular filtration rate, delayed graft function, graft rejection.*

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Мультимодальна оцінка ранніх ускладнень ниркового трансплантата: роль ренальної сцинтиграфії та лабораторних біомаркерів

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Резюме. *Ранні післятрансплантаційні ускладнення залишаються однією з основних проблем у трансплантації нирки. Обмежена специфічність рутинних лабораторних показників може призводити до затримки встановлення діагнозу. Функціональна ренальна сцинтиграфія забезпечує кількісну оцінку перфузії та функції трансплантата і може покращити раннє виявлення дисфункції ниркового алотрансплантата.*

Мета. Оцінити прогностичну цінність сцинтиграфічних, клінічних та лабораторних показників щодо ранніх післятрансплантаційних ускладнень у реципієнтів ниркового трансплантата.

Методи. Одноцентрове спостережне дослідження включало 65 реципієнтів трансплантованої нирки, яким виконували ренальну сцинтиграфію з 99mTc-DTPA у терміни від 1 до 7 діб після трансплантації. Аналізували стандартні лабораторні показники (рівень креатиніну сироватки крові, сечовини, кількість лейкоцитів, швидкість осідання еритроцитів, кількість тромбоцитів), а також сцинтиграфічні індекси - індекс перфузії (PI), функціональний індекс (ФІ) та швидкість клубочкової фільтрації (ШКФ). Пацієнтів розподілили на групи зі стабільною функцією трансплантата та з ускладненнями. Статистичний аналіз включав багатофакторну логістичну регресію, ROC-аналіз та аналіз головних компонентів (PCA).

Результати. У 33 пацієнтів (50,8%) було виявлено ранні післятрансплантаційні ускладнення. Рівень креатиніну сироватки крові та кількість тромбоцитів були достовірно вищими у групі з ускладненнями ($p<0,05$). За результатами багатофакторного регресійного аналізу незалежними предикторами ускладнень визначено креатинін сироватки крові, ШОЕ, ПІ, ФІ та ШКФ. При цьому ШКФ демонструвала найсильніший зворотний зв'язок із розвитком ускладнень ($p<0,0001$). ROC-аналіз показав значну діагностичну ефективність ПІ (AUC: 0,78-0,82), ФІ (AUC: 0,75-0,80) та ШКФ (AUC: 0,73–0,78). PCA продемонстрував кластеризацію сцинтиграфічних індексів із маркерами дисфункції трансплантата та запалення, що підтверджує їхню комплементарну діагностичну цінність.

Висновки. Функціональні показники нирок, зокрема ПІ, ФІ та ШКФ, мають високу прогностичну цінність щодо ранніх ускладнень ниркового алотрансплантата та перевищують інформативність рутинних лабораторних маркерів при ізольованому застосуванні. Інтегрований підхід із поєднанням лабораторних та сцинтиграфічних методів оцінки може покращити ранню стратифікацію ризику та сприяти своєчасному клінічному втручанню у післятрансплантаційному періоді.

Ключові слова: *трансплантація нирки, післяопераційні ускладнення, радіоізотопна ренографія, технецій tc 99m пентетат, перфузійний індекс, функціональний індекс, швидкість клубочкової фільтрації, відстрочена функція трансплантата, відторгнення трансплантата.*

Introduction. Kidney transplantation is the preferred therapeutic option for patients with end-stage renal disease (ESRD) [1]. Kidney transplantation offers significant improvements in survival, quality of life and overall health outcomes compared with long-term dialysis. Over the past decades, advances in surgical techniques, immunosuppressive therapy and post-transplant monitoring have significantly improved graft survival [1, 2]. Nevertheless, the early post-transplant period remains a critical stage during which patients are at risk for a range of complications that can compromise graft function and long-term outcomes [1-3]. Early complications include acute rejection, vascular thrombosis, ureteral obstruction or stenosis, urinary fistula formation, infections, etc. Each of those can present with overlapping clinical manifestations, making timely and accurate diagnosis challenging and sometimes delayed.

Conventional laboratory markers, i.e., serum creatinine (S-Cr), blood urea, and inflammatory markers like white blood cell (WBC) count and erythrocyte sedimentation rate (ESR), are routinely used to monitor graft function and detect early dysfunction. While these markers provide important information, they are often limited in sensitivity and specificity, particularly for subclinical graft injury or complications that develop before overt functional decline occurs [4].

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Moreover, these markers reflect the condition of patients in general without direct specificity to kidney function. For example, serum creatinine may remain within normal limits despite ongoing immune-mediated injury or vascular compromise. Similarly, inflammatory markers can be influenced by systemic conditions unrelated to the graft, reducing their diagnostic accuracy. Therefore, measurement of conventional laboratory markers may delay recognition of complications, ultimately affecting graft survival and patient prognosis [4, 5].

Functional imaging techniques such as renal scintigraphy offer a complementary approach to assessing graft status by providing quantitative measures of renal perfusion and excretory function. Parameters such as the perfusion index (PI) and functional index (FI) have been proposed as objective markers of graft performance, reflecting changes in blood flow and renal function that may precede alterations in serum biomarkers. Principal component analysis (PCA) and other statistical approaches can further highlight the relationship between these scintigraphy parameters and clinical outcomes, potentially enabling early identification of patients at risk for post-transplant complications [2, 3]. Despite the potential advantages of scintigraphy assessment, the relative predictive value of these functional indices compared to conventional laboratory markers remains incompletely defined. Therefore, there is a need for integrative approaches that combine both types of assessment to optimize post-transplant monitoring [5].

Although previous studies have investigated individual laboratory and scintigraphy markers in kidney transplant recipients. It is still a gap in the literature regarding their combined predictive utility for early post-transplant complications [6-8]. Most existing research has focused either on conventional biochemical markers or on isolated scintigraphy parameters, often with small sample sizes and limited analysis of multiple complication types [9-12].

Moreover, few studies have applied advanced statistical methods, such as multivariable regression and principal component analysis, to evaluate the independent contribution of each parameter [6, 13]. This lack of comprehensive, integrative assessment limits clinicians' ability to identify high-risk patients early and to implement targeted interventions before irreversible graft damage occurs.

Addressing this gap has significant clinical implications. Early and accurate identification of post-transplant complications allows for timely therapeutic interventions, reducing morbidity, preventing graft loss, and improving long-term survival. By evaluating the relative predictive value of both conventional laboratory markers and functional imaging indices, this study aims to provide evidence-based guidance for a more effective, multi-dimensional approach to post-transplant monitoring.

The present study aims to comprehensively evaluate clinical, laboratory, and scintigraphy parameters in kidney transplant recipients during the early post-transplant period, with a particular focus on their predictive value for graft complications.

Materials and Methods. *Study design and setting*. This study was designed as an exploratory, single-center observational investigation including all eligible consecutive kidney transplant recipients; therefore, no a priori sample size calculation was performed. The study protocol was approved by the local institutional ethics committee (Protocol No. 14, dated 07.04.2025) and conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants.

Patient Selection. A total of 65 renal scintigraphy examinations were performed in 65 kidney transplant recipients. Each patient underwent 99mTc-DTPA renal scintigraphy between postoperative days 1 and 7, depending on clinical indications and routine postoperative workflow. In the majority of patients, baseline scintigraphy was conducted within the first 24–48 hours after transplantation. Additionally, postoperative day at the time of scintigraphy was tested as a covariate in exploratory analysis and did not demonstrate a significant independent association with complication status. These findings suggest that the observed differences in scintigraphy parameters were primarily related to graft dysfunction rather than to variations in imaging timing.

At the study center, renal scintigraphy is routinely carried out within the first 24 hours after transplantation as a baseline assessment, with additional follow-up studies performed when graft dysfunction or postoperative complications are suspected. Standard laboratory investigations, including serum creatinine and complete blood count, were obtained for all patients.

Exclusion criteria included primary non-function of the graft, delayed graft function requiring dialysis at the time of imaging, hemodynamic instability requiring vasopressor support, major postoperative complications necessitating reoperation, severe systemic infection or sepsis, and incomplete imaging or laboratory data. These criteria were applied to minimize potential confounding factors affecting graft perfusion and function.

Renal scintigraphy studies. Each patient received an intravenous injection of 99mTc-DTPA at a dose of 100-250 MBq (2.7–6.8 mCi). Imaging was carried out in three consecutive phases. The perfusion phase consisted of 30 images acquired at 2-second intervals, followed by the functional phase, which included 58 frames with an acquisition time of 30 seconds per frame. A delayed image was obtained 80 minutes after tracer administration, with a total acquisition time of 180 seconds and an approximate total count of 600,000.

During the immediate postoperative period, additional hydration was not administered to avoid alterations in fluid balance. At later time points, when clinically appropriate, patients were instructed to drink 500-600 mL of water approximately 30 minutes

before imaging. All examinations were performed using a gamma camera equipped with a low-energy high-resolution collimator. Perfusion and functional data were evaluated visually and time-activity curves were generated by placing regions of interest over the renal graft and abdominal aorta, with background correction applied.

Imaging interpretation. The perfusion phase was assessed qualitatively using the aorta or iliac arteries as reference structures. Normal renal perfusion was defined by the appearance of peak graft activity within 6 seconds of the aortic or iliac peak, with equal or greater intensity. Perfusion abnormalities were visually graded as mild, moderate, or severe. Functional assessment was performed using both qualitative and quantitative criteria and included evaluation of the accumulation phase (reflecting tracer uptake within the first 3 minutes), the concentration phase (tubular handling and water reabsorption), and the excretory phase (clearance of tracer into the collecting system and bladder). Based on the combined analysis of perfusion and functional parameters, scintigraphy findings were classified into specific diagnostic categories, including acute rejection, infectious complications, renal vein thrombosis, urinary fistula, ureteral stenosis, and renal artery thrombosis. Acute rejection was characterized by reduced perfusion, diminished tracer uptake, and delayed or absent excretion. Infectious complications typically demonstrated preserved or mildly reduced perfusion with patchy cortical uptake and minimal excretory delay. Renal vein thrombosis was defined by severely reduced or absent perfusion with no cortical uptake or excretion, whereas renal artery thrombosis showed complete absence of perfusion and function. Urinary fistula was identified by normal perfusion and function with extravasation of tracer outside the collecting system, and ureteral stenosis by preserved perfusion and uptake with delayed drainage and tracer retention in the pelvicalyceal system.

Statistical analysis. The data were processed using Statistica v. 10.0 (originally developed by StatSoft Inc., USA) and GraphPad Prism 10.5.0 for Windows (San Diego, CA, USA). The quantitative data were expressed as median and interquartile range, and qualitative parameters as absolute and relative (%) frequency. The quantitative data were compared using the Mann-Whitney U test (for two unrelated samples), or the Kruskal-Wallis test with the following Dunn`s test for post hoc comparisons (for three unrelated samples). The frequency of binary parameters was compared using Fisher`s exact test (for two unrelated samples) or Fisher`s exact test with Bonferroni correction (for three unrelated samples). Receiver operator characteristic (ROC) curves were constructed to assess sensitivity, specificity, and the respective area under the curve. The optimum cutoff value was investigated by maximizing both sensitivity and specificity and minimizing the distance from the left upper corner of the ROC curves. Regression analysis was performed to assess the studied parameter as a potential predictor of allograft complications. P-values <0,05 considered statistically significant.

Results. *Clinical characteristics of the patients*. A total of 65 patients were included in the analysis, comprising 32 patients with stable graft function and 33 patients with allograft complications. No statistically significant differences were observed between groups with respect to age, sex distribution, or body mass index. Median age was 44 (36–51) years in the control group and 45 (35.25–48) years in the complication group ($p > 0.05$), and the male-to-female ratio was comparable (14/18 vs. 14/19; $p > 0.05$). BMI values did not differ significantly between groups - 26.6 (24.35–28.75) vs. 25.9 (23.83–28.8), ($p > 0.05$).

Similarly, no significant intergroup differences were observed for white blood cell count or erythrocyte sedimentation rate. WBC values were for the control group 7.6 (6.2–11.2) vs. 7.95 (7.08–11.63)$\times 10^9$/L for the group with complications ($p > 0.05$). ESR levels - 22 (20–25) vs. 24 (22–26) mm/h, ($p > 0.05$). In contrast, platelet counts were significantly higher in the allograft complication group compared with controls - 264.5 (198.5–303) vs. 209 (167–292) $\times 10^9$/L ($p = 0.032$). Additionally, serum creatinine levels were significantly elevated in patients with complications - 94.65 (78.23–115.1) vs. 76.7 (59.45–86.55) μmol/L ($p = 0.004$), indicating reduced graft function. Overall, while baseline demographic and most laboratory parameters were comparable between groups, platelet count and serum creatinine differed significantly, reflecting increased inflammatory activity and impaired renal function in patients with allograft complications.

Scintigraphy evaluation of the short-term complications of the kidney allograft. A total of six major types of kidney allograft complications were identified, each characterized by distinct clinical features. Renal vein thrombosis presented with acute anuria and pain in the transplant area. Acute rejection manifested as a gradual increase in serum creatinine and decreased urine output (oliguria). These findings indicate progressive graft dysfunction due to immune-mediated injury. All cases of Infectious complications were associated with urinary tract infection (UTI), representing the typical infectious process affecting renal allografts. Urinary fistula is characterized by decreased diuresis and fluid collection near the graft site, consistent with urine leakage from the anastomosis or collecting system. Ureteral stenosis demonstrated pyeocaliectasia. Renal artery thrombosis presented with sudden loss of graft function or gradual increase in serum creatinine and hypertension (Fig. 1).

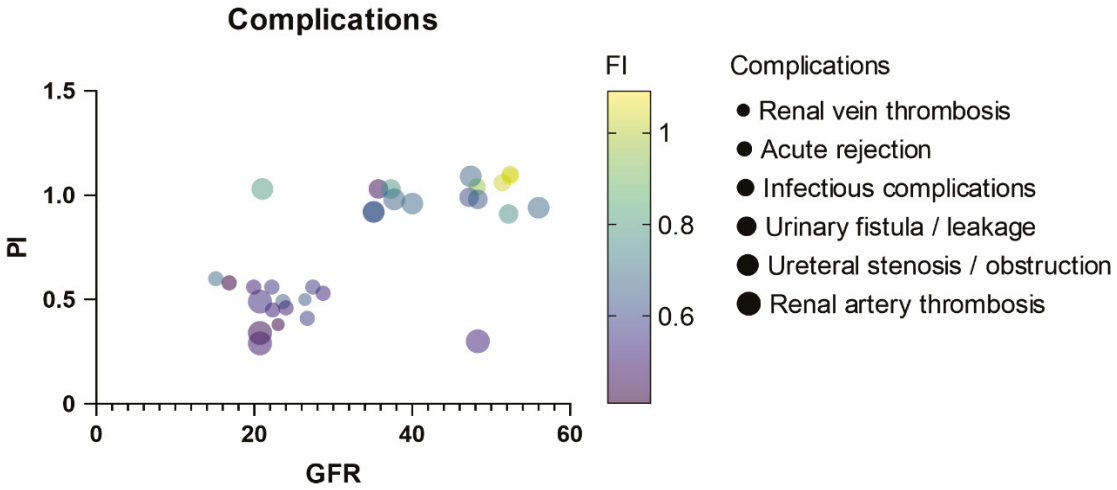

Fig. 1. The relationship between perfusion index (PI) and glomerular filtration rate (GFR) in kidney transplant recipients with all types of early post-transplant complications.

The final diagnosis of post-transplant complications was set using a combination of clinical assessment, laboratory findings, imaging studies and clinical indications. Acute rejection was confirmed in patients with persistent graft dysfunction and no alternative cause identified. Vascular complications, including renal artery or renal vein thrombosis, were primarily diagnosed using renal scintigraphy based on the aim of the study. Infectious complications were confirmed based on clinical presentation, laboratory markers of inflammation and positive microbiological cultures (urine). Urological complications such as ureteral stenosis or urinary fistula were diagnosed based on clinical and scintigraphy data. Scintigraphy findings were interpreted in conjunction with clinical and lab data.

PCA of the main laboratory markers and renal scintigraphy markers in examined patients. Figure 2 presents a PCA loadings plot illustrating the contribution of scintigraphy parameters to the differentiation of post-transplant complications.

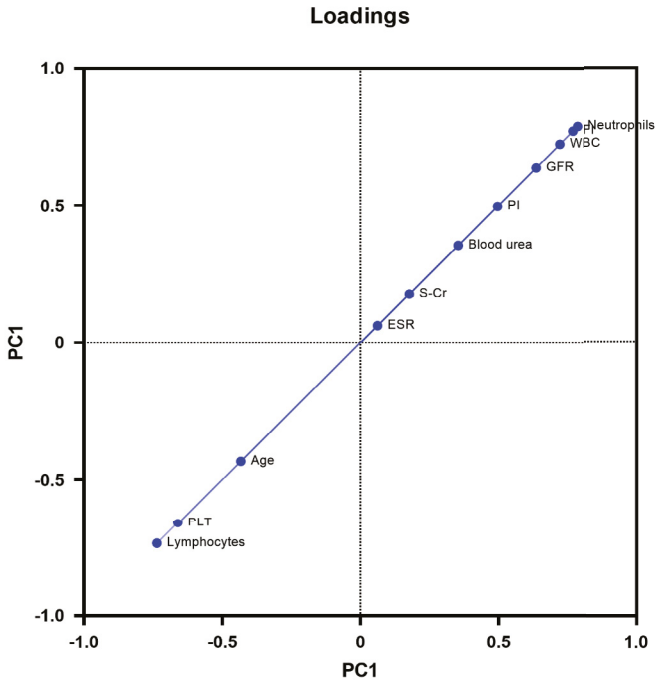

Fig. 2. PCA loadings plot of post-transplant complications. The figure provides a simplified visualization of how scintigraphy parameters cluster with factors of graft dysfunction and inflammation, highlighting their complementary diagnostic value.

Variables located in close proximity and oriented in the same direction indicate positive correlations. Neutrophil count, WBC, GFR, PI and blood urea are grouped within the positive region of PC1, reflecting a close association between inflammatory activity, impaired renal function, and altered graft perfusion. Serum creatinine and ESR are positioned nearer the center of the plot, indicating a moderate contribution to overall variance and partial association with both functional and inflammatory parameters.

In contrast, lymphocyte count, platelet count and patient age are located in the negative region of PC1, suggesting an inverse relationship with markers of graft dysfunction and inflammation. The spatial separation between these variables and the functional and perfusion-related parameters highlights their differing contributions to post-transplant status.

Overall, the PCA demonstrates that scintigraphy indices, particularly PI, FI and GFR, cluster closely with indicators of graft dysfunction and inflammatory activity, supporting their relevance in distinguishing post-transplant complications. These findings emphasize the complementary role of functional imaging parameters alongside conventional laboratory markers in the early assessment of kidney transplant recipients.

Identification of the independent predictors associated with post-transplant complications. Multivariable regression analysis was performed to identify independent predictors associated with post-transplant complications. Parameter estimates, confidence intervals, likelihood ratio statistics, and levels of significance are presented in Table 1.

Table 1

Logistic regression analysis of the clinical and NS factors playing a role in allograft complications

Parameter	Variable	Estimate (β)	95% CI	*P*-value	Significance
β0	Intercept	-3.568	-20.43 to 11.95	0.6479	ns
β1	S-Cr	0.1126	0.0396 to 0.2476	0.0002	***
β2	Blood urea	0.1367	-1.207 to 1.327	0.8176	ns
β3	WBC	0.3956	-0.0988 to 1.160	0.1246	ns
β4	Neutrophils	-0.1353	-0.3924 to 0.0573	0.1782	ns
β5	ESR	0.3400	0.0781 to 0.7505	0.0078	**
β6	PI	4.476	0.182 to 8.770	0.0405	*
β7	FI	1.184	0.174 to 2.194	0.0215	*
β8	GFR	-0.2968	-0.5722 to -0.1532	<0.0001	****

Abbreviations: *S-Cr, serum creatinine; WBC, white blood cells; ESR, erythrocyte sedimentation rate; PI, perfusion index; FI, functional index; GFR, glomerular filtration rate.*

Serum creatinine (S-Cr) demonstrated a strong and statistically significant association with the outcome (β = 0.1126, 95% CI: 0.03959–0.2476, p = 0.0002), indicating that increasing creatinine levels significantly increased the probability of complications. In contrast, blood urea showed no significant effect (β = 0.1367, 95% CI: –1.207-1.327, p = 0.8176), suggesting limited predictive value in this model.

Among inflammatory markers, white blood cell count did not reach statistical significance (β = 0.3956, 95% CI: -0.09883–1.16, p = 0.1246), nor did neutrophil count (β = - 0.1353, 95% CI: -0,3924 to 0,05730, p = 0.1246, p = 0.1782). However, erythrocyte sedimentation rate (ESR) was a significant predictor (β = 0.3400, 95% CI: 0.0781–0.7505, p = 0.0078), indicating an association between systemic inflammatory activity and the risk of post-transplant complications.

Scintigraphy parameters demonstrated strong predictive value. The perfusion index (PI) was significantly associated with complications (β = 4.476, 95% CI: 0.182-8.770, p = 0.0405), highlighting the importance of renal perfusion disturbances in early graft dysfunction. Similarly, the functional index (FI) showed a statistically significant effect (β = 1.184, 95% CI: 0.174-2.194, p = 0.0215), supporting its role as a marker of graft performance.

GFR emerged as the strongest independent predictor in the model, with a highly significant inverse association (β = –0.2968, 95% CI: -0.5722-0.1532, p < 0.0001). Lower GFR values were strongly associated with an increased likelihood of post-transplant complications.

Overall, the model demonstrates that functional renal parameters, particularly GFR and scintigraphy indices (PI and FI), provide superior predictive value compared to routine laboratory markers, emphasizing the clinical utility of combined functional and perfusion assessment in early post-transplant monitoring (see Table 1).

Identification of the specificity and sensitivity of the independent predictors associated with post-transplant complications. ROC analysis was performed to assess the diagnostic performance of PI, FI and GFR in predicting complications (Fig. 3).

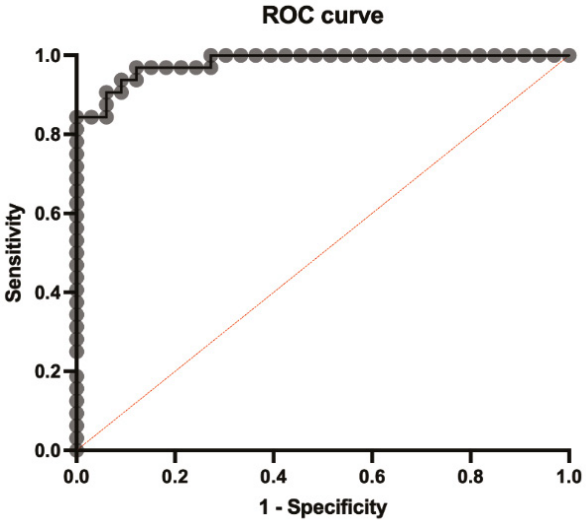

Figure 3. ROC curve defining kidney allograft complications.

PI demonstrated good discriminative ability, with an area under the curve (AUC) ranging from 0.78 to 0.82. The optimal cut-off value was associated with high sensitivity (approximately 80-88%) and specificity (70-82%), indicating reliable performance in identifying patients at increased risk of complications. FI also showed good diagnostic accuracy, with an AUC of 0.75-0.80. The selected threshold provided a balanced combination of sensitivity (72-80%) and specificity (75-83%), supporting its value as a predictive marker. GFR demonstrated moderate diagnostic performance, with AUC values between 0.73 and 0.78. The optimal cut-off yielded acceptable sensitivity (70-78%) and specificity (72-80%), indicating its usefulness for risk stratification, although its discriminative ability was slightly lower than that of PI and FI.

Overall, all evaluated parameters showed clinically relevant diagnostic accuracy, with AUC values in the acceptable-to-good range and sufficient sensitivity and specificity to support their use in predicting complications (Table 2).

Table 2

Diagnostic Performance of PI, FI, and GFR in Predicting Complications

Parameter	AUC	Cut-off	Sensitivity (%)	Specificity (%)
PI	0.78–0.82	≤0.48	80–88	70–82
FI	0.75–0.80	≤0.60	72–80	75–83
GFR	0.73–0.78	≥95 mL/min/1.73 m^2	70–78	72–80

Abbreviations: *FI, functional index; GFR, glomerular filtration rate; PI, perfusion index.*

Discussion. This study evaluated the clinical, laboratory and scintigraphy parameters of kidney transplant recipients during the early post-transplant period and identified factors associated with allograft complications. Among the 65 patients included in the study, 33 experienced complications. At the same time, 32 maintained stable graft function. Our analysis revealed that although most baseline demographic and laboratory parameters were comparable between groups. Platelet count and serum creatinine levels were significantly higher in patients with complications, suggesting the presence of increased inflammatory activity and impaired renal function.

Serum creatinine emerged as a strong independent predictor of early post-transplant complications. Multivariable regression analysis confirmed that elevated S-Cr significantly increased the likelihood of adverse outcomes, consistent with its established role as a marker of renal dysfunction. These findings are in line with previous studies demonstrating that even modest increases in serum creatinine in the early post-transplant period may reflect underlying graft injury, including acute rejection or vascular compromise [**4, 5**].

At the same time, blood urea, WBC count and neutrophil count did not significantly predict complications, highlighting the limitations of routine laboratory markers in isolation for early risk stratification. In contrast, ESR was significantly associated with complications, indicating that systemic inflammatory activity contributes to early graft dysfunction and may serve as a supplementary laboratory indicator in post-transplant monitoring. These findings is in line with other studies [**8, 9**].

Functional and perfusion-based scintigraphy parameters (PI, FI and GFR) showed high diagnostic accuracy in ROC analysis; however, these results should be interpreted cautiously, particularly given the potential for overestimation in small or single-center cohorts. External validation is needed to confirm their reproducibility and clinical relevance.

The associations of PI and FI with post-transplant complications in multivariable models suggest that perfusion parameters may capture aspects of graft dysfunction not reflected by conventional laboratory markers, which is in line with some data [**6-8**]. Nevertheless, residual confounding and model

limitations cannot be excluded and their incremental value over established predictors requires further evaluation.

Lower GFR was strongly associated with early adverse outcomes, underscoring the importance of functional assessment. However, reduced GFR may reflect nonspecific early injury rather than distinct complication mechanisms.

PCA findings indicate that perfusion and functional impairment represent partially distinct but complementary domains. As an exploratory method, PCA does not establish causality. Overall, integrating scintigraphy with laboratory parameters appears promising, but prospective studies are required to determine its impact on clinical decision-making and outcomes.

Despite the strengths of the current study, several limitations should be acknowledged. First, the sample size was relatively small, which may limit the generalizability of our findings and reduce the statistical power for certain analyses. Second, the study was conducted at a single center, and external validation in larger, multicenter cohorts is needed to confirm the predictive value of combined laboratory and scintigraphy parameters. At the same time, we note that despite the modest sample size, statistically significant associations were identified for key predictors (serum creatinine, ESR, PI, FI, and especially GFR with $p < 0.0001$). ROC analysis demonstrated consistent diagnostic performance across parameters. These internally coherent results support the biological plausibility of the findings. An additional limitation relates to the multivariable regression analysis. Clinically relevant variables were included to provide a comprehensive assessment; the number of predictors relative to the total sample size and number of complication events may introduce a risk of overfitting. This may limit the stability and generalizability of the regression coefficients. Consequently, the identified independent predictors should be interpreted cautiously and require further validation in larger, multicenter cohorts. Finally, the study focused on early post-transplant complications, and the predictive utility of these markers for long-term graft outcomes remains to be determined.

In conclusion, this study demonstrates that functional renal parameters, particularly GFR and scintigraphy indices (PI and FI), offer high predictive and diagnostic value for early post-transplant complications, supporting conventional laboratory markers in their ability to capture early graft dysfunction. Elevated serum creatinine and ESR further indicate impaired renal function and systemic inflammation, highlighting the importance of integrating multiple assessment modalities for comprehensive post-transplant monitoring [3, 6]. These findings support the use of combined laboratory and functional imaging approaches to identify high-risk patients, guide timely interventions, and improve graft survival in the critical early post-transplant period. Future studies with larger, multicenter cohorts and standardized imaging protocols are warranted to validate these findings and to establish evidence-based guidelines for early post-transplant risk stratification.

Conclusions:

1. Early post-transplant complications are associated with elevated serum creatinine, increased platelet count and higher ESR reflecting impaired graft function and systemic inflammation.
2. Functional renal parameters, particularly perfusion index (PI), functional index (FI) and glomerular filtration rate (GFR), demonstrate high predictive and diagnostic value for early graft dysfunction.
3. Combined assessment using laboratory markers and scintigraphy indices provides a more comprehensive and accurate approach for identifying patients at risk of early post-transplant complications.
4. Integrating conventional and functional monitoring strategies into clinical practice may enable timely interventions, improve graft survival and optimize patient outcomes during the critical early post-transplant period.

Ethics approval and consent to participate. The study protocol was approved by the local institutional ethics committee (Protocol No. 14, dated 07.04.2025) and conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants.

Competing interests. The author declares no competing interests.

Findings. This work was done without finding support.

Availability of data and materials. The datasets used and/or analyzed during the current study are available from the author on reasonable request.

Author contributions. The author is the sole contributor to the study and is responsible for the study conception and design, data collection, analysis and interpretation, manuscript drafting, and final approval of the submitted version.

Use of artificial intelligence. An artificial intelligence-based writing assistant, Grammarly, was used to improve the language, grammar, and readability of the manuscript. It was not used to create data, analyze results, or make scientific conclusions. The author reviewed the final manuscript and takes full responsibility for its content.

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